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The Wings of ICARUS

by ABRAHAM HERTZBERG

Hypersonic Shock Tunnel Developed at C.A.L. Simulates Flight at 10,000 m.p.h. and Faster

The wings of Icarus, devised of feathers and wax, were inadequate for high altitude flight. According to Greek mythology, Icarus' wings melted as he soared too near the sun and he plummeted into the sea. Modern "wings of steel," the guided missile, also could melt in the extremely high temperatures encountered in hypersonic flight. However, the hypersonic shock tube, testing device described by Mr. Hertzberg in this article, is one reason for hope the Icarian legend will have no parallel in modern flight.

IN less than a decade the use of jet propulsion has multiplied the speed of aircraft by more than a factor of ten. By providing great power in a small package, the jet engine has removed the power barrier to high velocities.

The question naturally arises: why so fast? After all, present-day transport aircraft can travel from coast to coast in less than the time between breakfast and dinner, and fighters already maneuver at speeds which tax the human body to its limits. However, there is an important and immediate military problem which in some ways is related to a man throwing a rock. The faster he throws it, the farther it goes, and when he wishes to throw it across four thousand miles, he must throw it at least 20,000 feet per second. If these velocities can be achieved by rocket propulsion, it will be possible to throw a missile from one continent to another.

An intercontinental missile is partly a space ship. It uses its fuel in the first few seconds of flight in accelerating to high velocity. It then proceeds in an orbit beyond the atmosphere and ultimately falls back through the air at an enormous velocity to strike its target. Figure 1 shows the orbit of

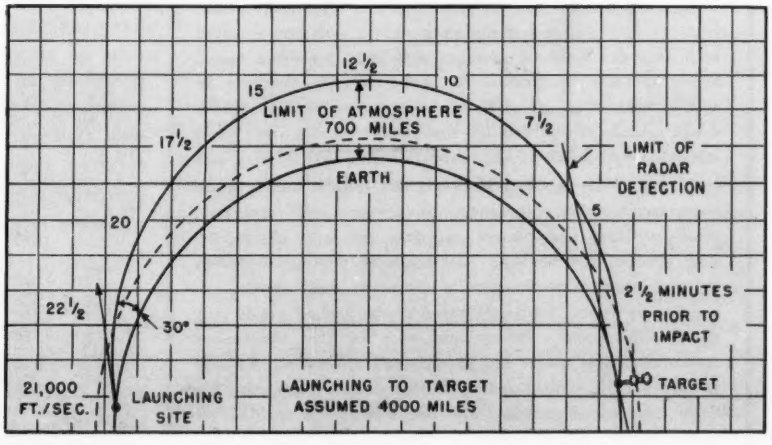
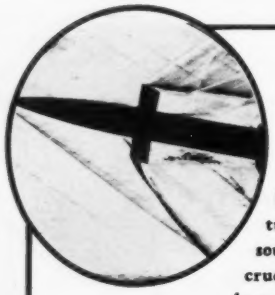


FIGURE 1 — Detail of typical rocket trajectory (reproduced from "Rocket Propulsion" by E. Burgess, London, 1952).

such a missile. The very speed of this missile makes it vitually unstoppable. These statements may have a somewhat Buck-Rogerish sound to them, but it should be emphasized again that these problems are now of immediate and practical importance. The intercontinental missile is no longer a dream of visionaries. It is a problem which today is occupying the serious attention of many scientists and engineers.

Let us think about the flight path of such a vehicle again. As previously stated, there is a brief period of flight through the atmosphere, followed by most of the trajectory above the atmosphere, then a diving re-entry. During re-entry the missile reaches its maximum velocity. It re-enters the atmosphere at high speed almost as if it were a flaming meteor. A meteor, by its impact and friction with the atmosphere, generally destroys itself. It rarely reaches the earth. How, then, can the missile be prevented from becoming another meteor and being destroyed by its own impact with the atmosphere before it can be used against the enemy? The techniques required cannot be discussed here, but they will call for the most careful and precise design on the part of the engineer.

The most direct way of testing a machine, particularly an aircraft, is to build a prototype and fly it. However, the problems of economy and locale in missile testing are vastly different from those encountered in conventional testing. After a few minutes the guided missile is a thousand miles away from the point of firing. Furthermore, each missile may cost more than the most expensive aircraft and is destroyed after each test. The slightest mistake during any of the intricate procedures of testing will totally destroy the effectiveness of the test. If, however, the conditions of flight can be brought into the laboratory, scientists and engineers will have at their fingertips many instruments that may be used to study this problem. They can afford to make mistakes and learn how to build their machines.



THE COVER

The photo insert at left, also reproduced on the cover page, is a schlieren photograph of a wing body interference model in a wind tunnel test at twice the speed of sound. The model has four wings in a cruciform pattern and in this test is in a 45° roll attitude. This photo shows one of the many models, each instrumented with over one hundred pressure taps, that are being tested under C.A.L.'s comprehensive basic research program in missile wing-body interference. Because supersonic missile wings are usually of smaller size relative to the body than subsonic airplane wings, the mutual interference of wing and body has more significant effects on missile aerodynamic characteristics than the designer may expect. In particular, missile stability and control are often critically affected by such mutual interference. This schlieren photograph shows the air density variation due to the many shock waves, expansion waves and vortices created as the airflow passes over the missile model. Photographs such as this supplement measurements of forces and pressures on the model, and help to give a basic understanding of the factors influencing the flight behavior of missiles. This test was run in the Convair operated U.S. Navy Bureau of Ordnance supersonic wind tunnel at Daingerfield, Texas, as part of the C.A.L. participation in the Bumblebee missile program. (Photo courtesy of that facility.)

THE HYPERSONIC SHOCK TUNNEL

The chief tool of the aeronautical engineer for the study of supersonic flight has been the wind tunnel and by use of the converging-diverging nozzle, supersonic velocities have been readily achieved. However, to test the intercontinental missile accurately, all the conditions of flight cannot be simulated in the conventional tunnel and a new technique has had to be devised. At present a promising technique is a modification of the shock tube called the hypersonic shock tunnel.

Why is the shock tunnel needed? The intercontinental missile in flight generates temperatures difficult to simulate in the conventional wind tunnel for, in expanding gases to the high velocity required, great cooling occurs. In fact, the cooling is so severe when hypersonic velocities are achieved that actual condensation of the air to a fog of liquid air may occur. To delay this condensation, the air may be heated before it is expanded. However, by examining the amount of expansion necessary to reach these extreme velocities (expansion ratios on the order of several thousand), it is found that just to avoid condensation, gas temperatures must be generated in the tunnel which are higher than the melting point of practical materials. Even if condensation can be avoided, the conventional tunnel has not simulated the conditions of flight. When the temperatures required to simulate true free flight are examined, temperatures approaching those of the sun's surface are noted. For example, a missile flying only at Mach 16 (16 times the speed of sound)* would have, at 60,000 feet, a theoretical temperature at its nose of about 6,000° Kelvin (see Figure 2), and it is proposed to go even faster. Therefore the conventional wind tunnel has had to be abandoned and the new concept developed. C.A.L.'s tunnel is the first type of facility developed capable of duplicating air temperatures encountered in hypersonic flight (Mach numbers greater than 5).

The question might be asked as to why such high temperatures must be simulated. Does the temperature of the gas itself affect the proposed design? The answer to this question is yes. At the temperatures encountered near the body of a missile, air is no longer an ideal gas. It breaks down from a relatively simple mixture of nitrogen and oxygen molecules to nitrogen and oxygen atoms and molecules, oxides of nitrogen,

*Mach number is defined as the ratio between the velocity of the gas and the local velocity of sound.

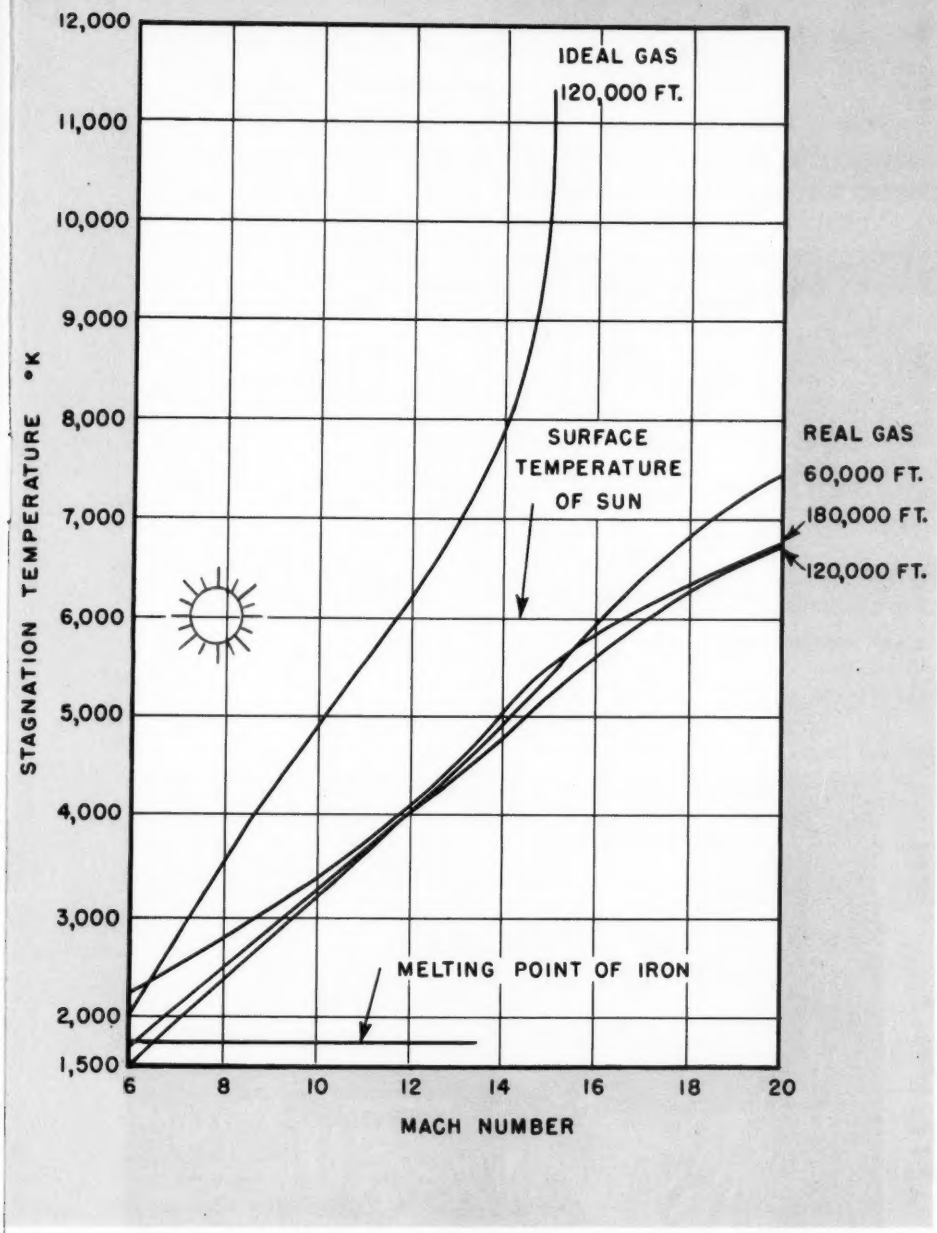


FIGURE 2 — Approximate maximum temperature of guided missile at various altitudes.

ions and electrons. These constituents directly affect the aerodynamics and raise many new problems in the proposed design. Since true hypersonic flight is to be studied, it has been necessary to find techniques to simulate these conditions in the laboratory. In recent years the researcher has been offered a relatively simple tool which creates these conditions in the laboratory for a brief instant. This device is called the shock tube.

Like many things which we regard as the latest innovation, it is actually quite an old discovery dating back to 1899. However, its potentialities for heating gases to extremely high temperatures have been exploited only recently. It has been established by several scientific research groups that temperatures even higher than three times that of the surface of the sun may be achieved in the shock tube.

HOW THE SHOCK TUBE WORKS

Essentially the shock tube consists of a relatively long pipe divided into two parts, the low-pressure and high-pressure chamber. When the experiment is ready to proceed, a thin diaphragm which separates the high-pressure and low-pressure regions is destroyed. Driver gas in the high-pressure chamber then explosively rushes into the low-pressure chamber which is filled with the gas we wish to study. Explosive action of the driver gas forces the gas in the low-pressure chamber ahead of it. Under these conditions, the gas in the low-pressure chamber does not have time to get out of the way in the conventional manner, but is forced to compress suddenly, and a shock wave develops in this gas.

This shock wave speeds down the tube ahead of the onrushing driver gas, compressing and accelerating the gas in the low-pressure tube. If high enough pressure is used in the driver gas, an extremely strong shock wave can be generated. (At C.A.L. shock Mach numbers in excess of 22 have been observed). If the tube can be made long enough (in some practical applications tubes of over 50 feet in length have been employed), a pocket of gas which increases in size with the length of the shock tube develops ahead of the rushing driver gas.

Temperatures far in excess of those needed for hypersonic flight testing may be generated in this pocket. The temperatures, pressure and velocity of the gases in the shock tube may be known to considerable accuracy. This point is very important in precise physical measurement. However, the gas is still not useful for hypersonic testing, for while it is very hot its Mach number is not correct. In fact, the Mach number is actually low, usually between two and three. Here gas is heated to extreme temperatures as well as accelerated to high velocity. Therefore, the flow Mach number still remains a relatively small number since the speed of sound increases with increasing temperatures.

However, at C.A.L. a trick has been borrowed from the conventional wind tunnel by inserting at the end of the shock tube an expanding nozzle which

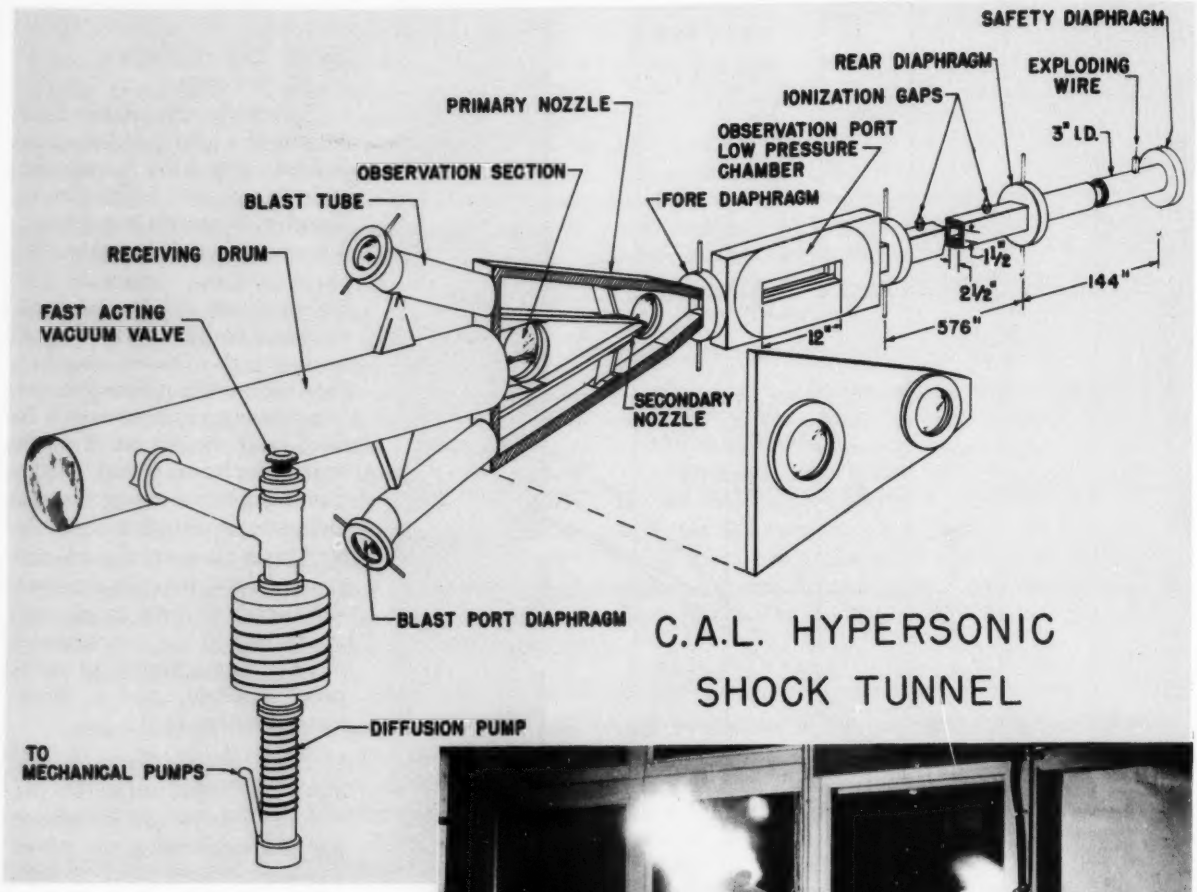


FIGURE 3 — C.A.L. Hypersonic Shock Tunnel.

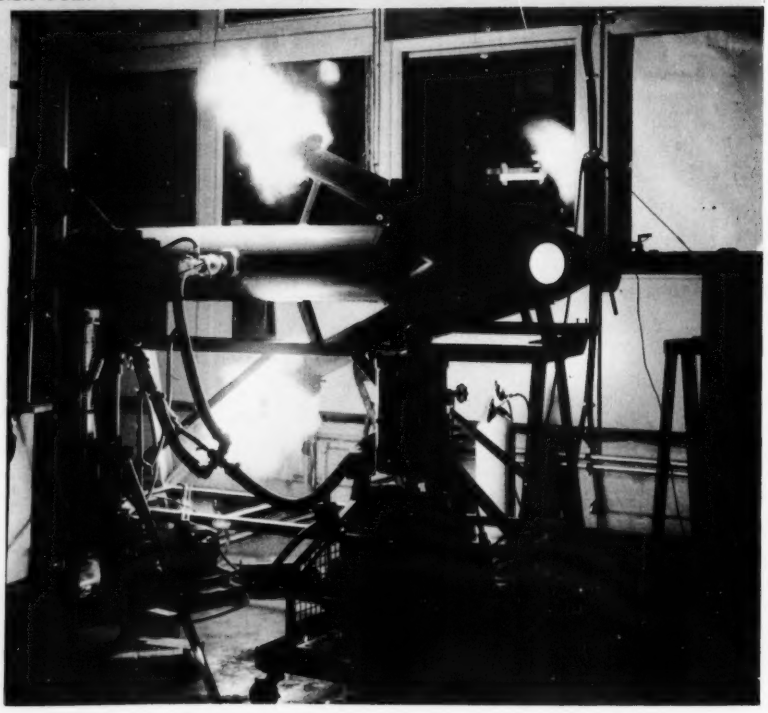


FIGURE 4 — The hypersonic impulse tunnel in operation at night. Air flow from the two escape ports becomes luminous upon striking the still air of the room.

allows the gas to expand to the proper Mach number. Since the gas has been highly preheated, the cooling of this expansion brings the test section temperature down to the desired level as the gas accelerates. Thus the gas in the test section may completely simulate the conditions of free hypersonic flight in the upper atmosphere. Figure 3 is a drawing of the C.A.L. hypersonic shock tunnel showing the main features. Figure 4 is a photograph of the shock tube in operation at night, taken by its own luminosity. In the test section, luminous shock waves may be seen at the bow of the test wedge.

To understand more fully how a shock tube works, let us examine the sketches in Figure 5 showing the shock tube in several stages of operation. In the first sketch, the shock tube is not yet in operation. In the next sketch, the driver has just been exploded, the diaphragm burst and the shock wave is on its way down the tube. It is possible now to follow both the passage of the shock wave down the tube and the

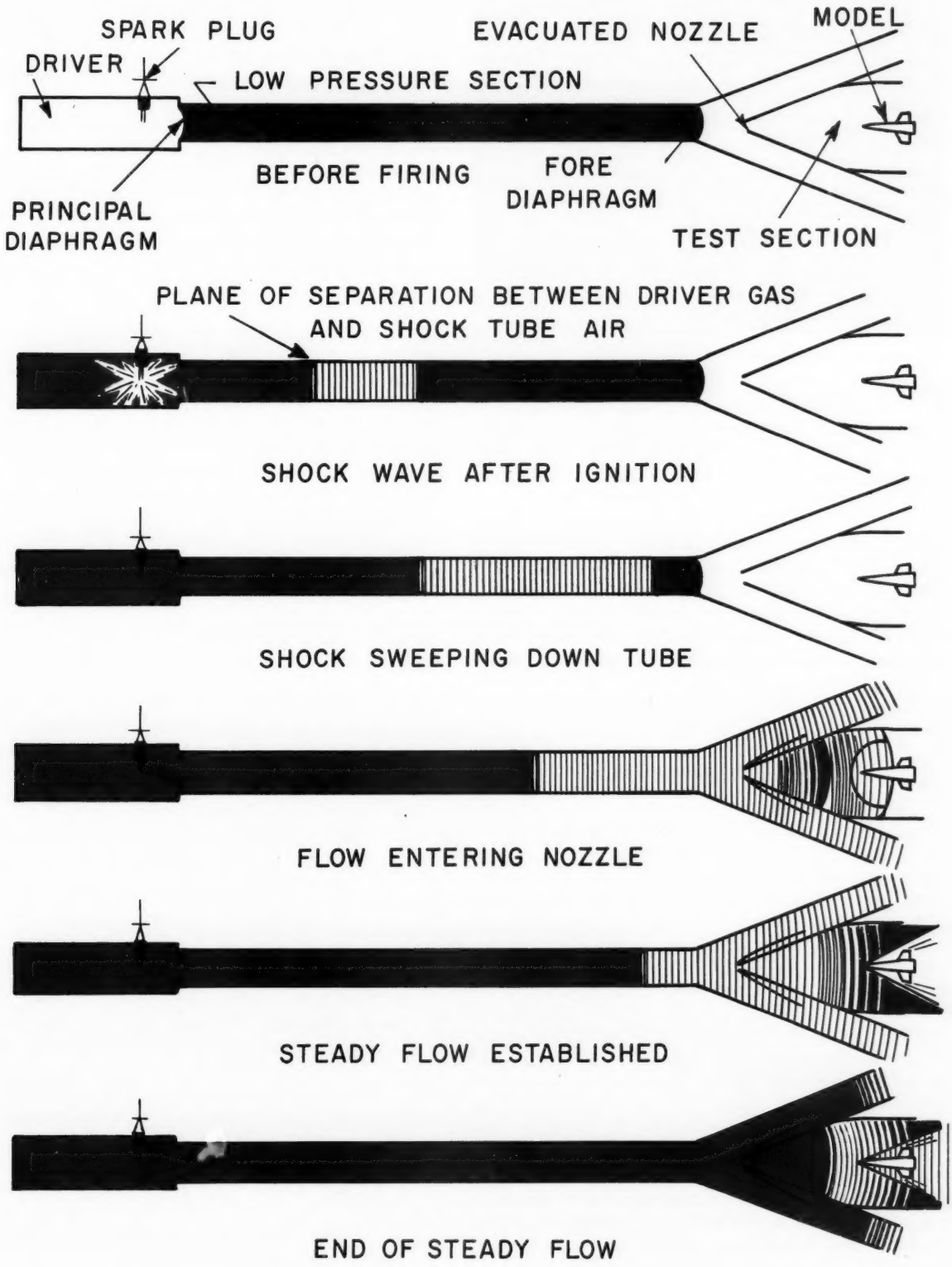


FIGURE 5 — Hypersonic shock tube in several stages of operation.

Photograph of possible missile configuration re-entering atmosphere where problems of drag and friction arise. Here the missile's nose is deflected downward from the true flight path of the missile. The luminosity about the missile model illustrates the danger of an unstable penetration into the atmosphere. Should a missile or rocket enter the atmosphere in such a position, it would burn up quickly.

region of gas accelerated by the driver gas as it expands into the dual expansion nozzle. The red region represents the expanding driver gas whereas the shaded region represents the gas in the low-pressure chamber which has been accelerated by the shock wave during its passage down the tube. The blue gas represents gas which has been expanded or is initially cool. It should be pointed out that the whole operation takes less than 10 one-thousandths of a second.

AN INSTRUMENTATION PROBLEM

The chief drawback to the shock tube is the extremely brief testing time available because of this short operating cycle. For example, the C.A.L. shock tube is approximately 50 feet long and this length yields practical testing times of about a millisecond. The testing time, which is the time for the testing gas from the shock tube to sweep through the nozzle, may be increased by increasing the length of the shock tube. However, studies on the instrumentation problem carried out at C.A.L. revealed that for all practical purposes, most of the important problems of hypersonic flight, particularly the heat transfer problem, can be investigated with testing times as brief as half a millisecond. Indeed, at the temperatures proposed for the work, long testing times are not possible. The shock tube would be reduced to a heap of slag if the testing time were over a few seconds. However, the problems of testing and measuring in this period of half a millisecond must not be underestimated. Great ingenuity will be necessary to provide useful data in the future.

OTHER USES OF THE SHOCK TUBE

The ability of the shock tube conveniently to bring high temperature gases into the laboratory has led to its exploitation in fields outside aerodynamics. For example, at C.A.L. the shock tube is being used for the study of high temperature chemical kinetics. By using a combination of closely controlled shock and expansion waves a sample of gaseous reactant can be processed through a controlled temperature the shape of which can often be tailored to the precise need. One of the first reactions tested in the laboratory was the formation of nitric oxide in air. In this experiment, a sample of air was heated to extremely high temperature; it was so high, in fact, that some of the nitrogen combined with the oxygen. Then, by the passage of an expansion wave through it, the gas was cooled so suddenly that the nitric oxide was left in the combined state after the experiment. Since nitrates are the basis of important fertilizers, this experiment suggests the exciting possibility that we may one day employ shock waves in air to manufacture fertilizer. Thus, by turning the force of explosions into plant food, the aeronautical engineer may have found a way of beating swords into plowshares.

REPORTS*

"A NEW SHOCK TUBE TECHNIQUE FOR THE STUDY OF HIGH TEMPERATURE GAS PHASE REACTIONS," Glick, H. S., Squire, W. Hertzberg, A.; Fifth International Combustion Symposium, Pittsburgh, Pa.

"FLOW PHENOMENA IN STARTING A HYPERSONIC SHOCK TUNNEL," Glick, H. S., Hertzberg, A., Smith, W. E.; C.A.L. Report No. AD-789-A-3; AEDC TN-55-16.

"MODIFICATIONS OF THE SHOCK TUBE FOR THE GENERATION OF HYPERSONIC FLOW," Hertzberg, A., Smith, W. E., Glick, H. S., Squire, W.; C.A.L. Report No. AD-789-A-2; AEDC TN-55-15.

"REAL GAS EFFECTS IN A HYPERSONIC SHOCK TUNNEL," Squire, W., Hertzberg, A., Smith, W. E.; C.A.L. Report No. AD-789-A-1; AEDC TN-55-14.

"SHOCK TUBES FOR HYPERSONIC FLOW," Hertzberg, A.; C.A.L. Report No. AF-702-A-1.

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AIRPLANES with VARIABLE STABILITY

Stability and Control Studies Aid in Aircraft Design

by WALDEMAR BREUHAUS

The first flight report on record describes the difficulty experienced by the pilot in controlling his plane. Orville Wright's diary for December 17, 1903, states: "I found the control of the front rudder quite difficult on account of its being balanced too near the center . . . thus (it) had a tendency to turn itself when started so that the rudder was turned too far on one side and then too far on the other." (See Figure 1). Ever since then aircraft designers have wrestled with problems involving the stability and control of the airplane.

The ultimate goal, of course, has been to obtain sufficient quantitative information to permit the design of new aircraft with satisfactory handling qualities. Thus, costly changes in the production of prototypes may be avoided. These quantitative design requirements can be obtained using aircraft with stability characteristics which can be modified over a wide range. In addition, anticipated handling qualities of a newly designed aircraft can be simulated prior to its completion, and the acceptability of unusual characteristics checked. Four of these aircraft, called "variable stability" airplanes, have been developed by C.A.L. (See Figure 2).

The problem of airplane stability is complex. Loosely speaking, the airplane is capable of many motions. It can move forward, sideways and up-and-down. Also, it is capable of rotation about axes in each of these three directions. An airplane, therefore, has six degrees of freedom, or, to put it another way, its overall motion may be considered to embody six different kinds (or components) of motion. For the relatively mild maneuvers found in ordinary flight the overall motion can be separated into two characteristic classes — longitudinal and lateral.

Longitudinal motion includes translational motions along the fore-and-aft and the vertical axes of the airplane as well as rotation (pitching) about the axis along the wing span. Lateral motion includes translational motion along the spanwise axis (sideslip) and rotation about the fore-and-aft and the vertical axes (rolling

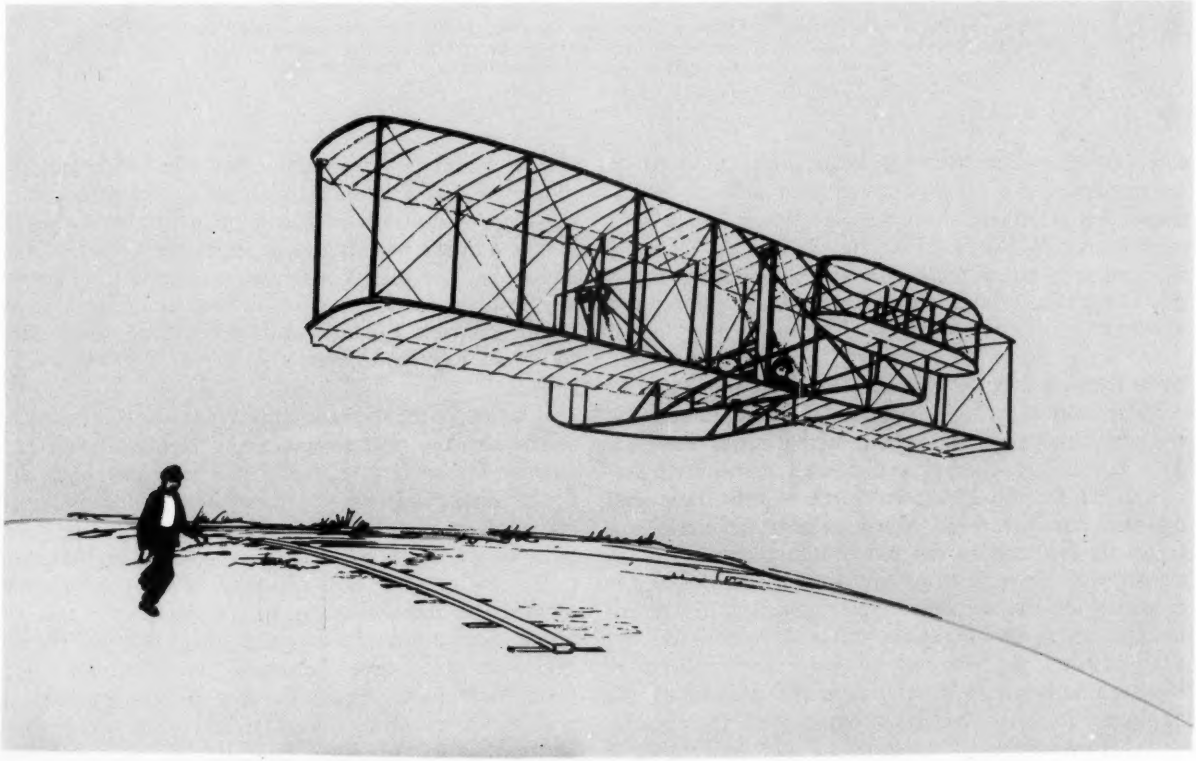

FIGURE 1 — The world's first successful flight by an airplane launched by its own power. Orville Wright, the pilot, reported control difficulties which occurred during this flight.

FIGURE 2 — This modified F-94A jet fighter is one of the variable stability airplanes operated by C.A.L.'s Flight Research Department. Its longitudinal control system is actuated by special hydraulic servos which permit wide variations of the stability and control characteristics of the airplane.

and yawing). Characteristic longitudinal motions of an airplane are usually observed as a pair of oscillations — a relatively short period motion and a long period motion known as the "phugoid." Lateral motions are observed as spiral (turning) flight and as the "Dutch roll" oscillation (a combined rolling and yawing).

MOTIONS OF AN AIRPLANE

The stability of an airplane is demonstrated by the way these motions die out with time if the pilot does nothing to correct a disturbed maneuver. Stability can be broken down further into static and dynamic considerations. Static stability, an important factor in determining the steady-state responses of an airplane to movement of its controls, describes the tendency of the airplane, once disturbed, to return towards its original flight condition. Dynamic stability deals with the time-varying motions which occur during such a return. It influences the motion of the airplane just after the pilot has moved its controls and before a steady response to this movement is reached. Dynamic stability is expressed by such things as the rate of decay of oscillatory motions or their rate of build-up if the ship is unstable. Although the stability of an airplane strongly affects its response to the control motions of the pilot, a further factor is involved in the handling qualities of the airplane: The opinion of the pilot concerning the controllability of his airplane is influenced by the forces he must exert on the controls and by the control motions necessary to obtain a given response.

Obviously the overall stability and control behavior of the airplane results from many factors. These frequently are so interrelated that pilots may have difficulty diagnosing the real cause of the unsatisfactory actions they observe. Thus, it is correspondingly difficult to specify quantitatively in advance the handling qualities which they will approve. If this can be done, however, in terms that can be translated to the design board, airplanes can be designed which will not require expensive and time-consuming modifications after flight tests have begun. Because of the number of variables determining overall stability, the specification of satisfactory handling qualities becomes complex. Nevertheless, these specifications must not be so complex as to prohibit practical design.

Although individual variation of relevant stability and control factors is an obviously desirable means for obtaining quantitative handling qualities data, the equipment for such tests was not available until recently. Quantitative data had been derived formerly by comparing the characteristics of airplanes which had satisfactory handling qualities with the characteristics of other airplanes which had unsatisfactory handling qualities. These tests were significant because their results began to supply designers with the desired quantitative specifications. They did not, however, adequately separate the effects of the variables. Furthermore, the test vehicles were unable to simulate foreseeable changes of handling qualities which might result from design trends. Use of airplanes without servo-operated variable stability systems required laborious and expensive physical changes for almost every modification to be evaluated.

SERVO-CONTROL SYSTEMS

Because control of the large, high-speed, modern military aircraft often exceeds the pilot's physical capabilities, power operation of controls is necessary. But full-power control prevents the pilot from feeling the aerodynamic reactions on the control surfaces. Hence, control "feel" must be obtained by artificial means. This raises the question as to whether these artificial forces must duplicate those produced aerodynamically. If the need for duplication does not exist, the design of the control system can be simplified. Hence, an answer must be found regarding the type of control forces which the pilot does require.

Fortunately, the increase in need for quantitative knowledge of aircraft handling qualities has been approximately paralleled by the development of high performance servo-control systems for aircraft. Installation of this type of equipment in an airplane permits simulation of wide variations of stability and control characteristics by simple changes of the sensitivities of the automatic control equipment. These sensitivity changes can be made during flight simply by turnng a control knob. Handling qualities can be modified through wide ranges and a number of configurations can be investigated within a single flight. When equipped with such servo devices an airplane becomes a highly versatile and useful research tool for the investigation of stability and control requirements. A large portion of activities in C.A.L.'s Flight Research Department has been devoted to the development of these variable stability aircraft and their use in flight investigation of handling qualities. This research largely has been sponsored by Wright Air Development Center, U. S. Air Force. The National Advisory Committee for Aeronautics and a small segment of the aircraft industry also have been active in this field.

Variable stability installations developed at C.A.L. (see Figure 3) have included a lateral control system (automatic control about the rolling and yawing axes), two longitudinal control systems (pitching) and an airplane incorporating both. The possibility of varying

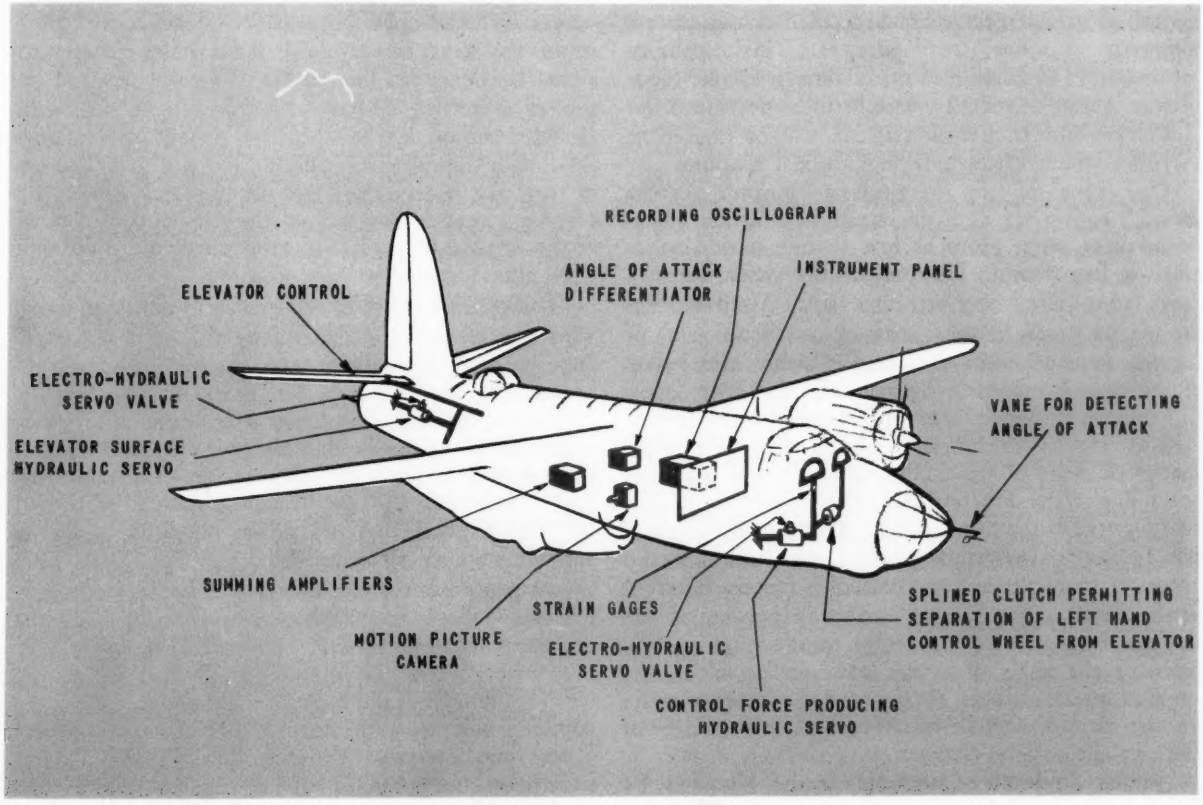

FIGURE 3 — Longitudinal control installation in a B-26 airplane. Location of the recording instrumentation is also shown.

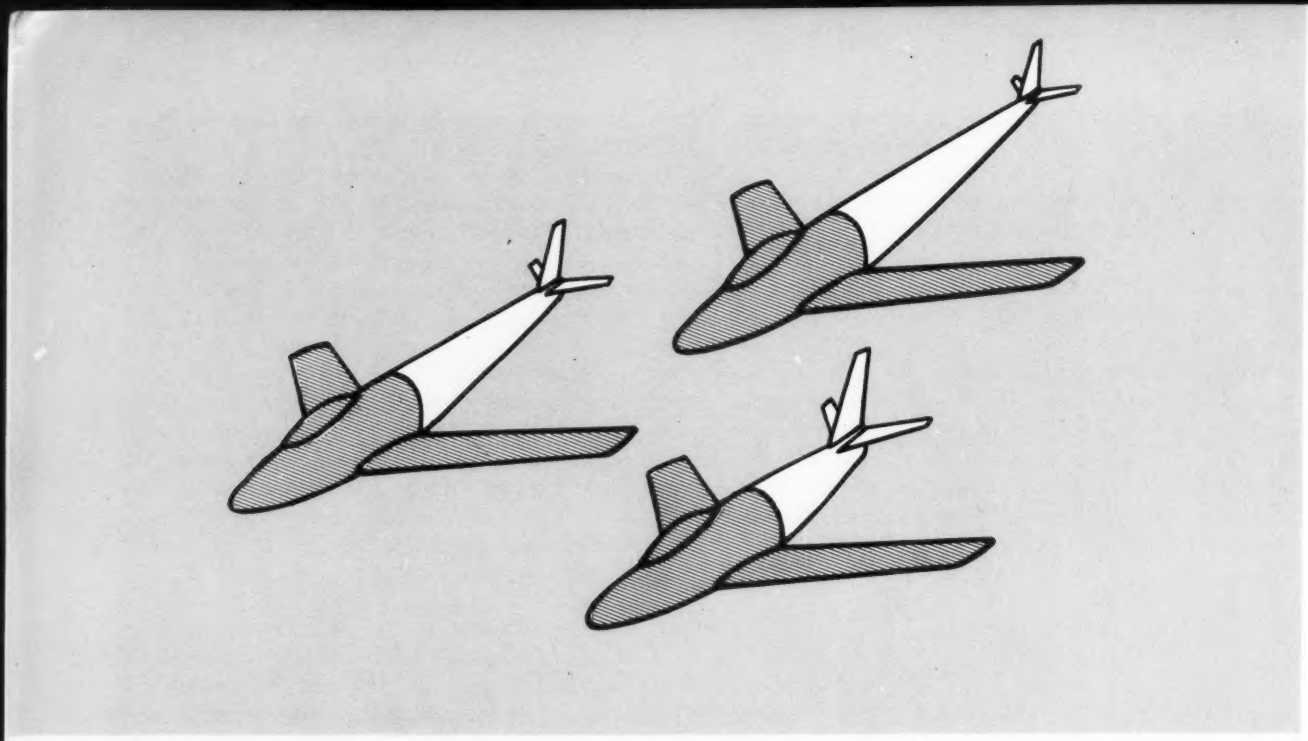

FIGURE 4 — The three sketches illustrate configurations which can be investigated during a single flight using variable stability equipment. This equipment makes the airplane fly as if its dimensions were changed.

the stability characteristics of these airplanes has caused them to be dubbed "Rubber Airplanes." Their effective dimensions can be changed by twisting a knob. They can be made to fly like airplanes with greater or less tail length, larger or smaller tail, varying center-of-gravity locations (see Figure 4). This capability permits rapid evaluation of many configurations. Since all the variable stability installations developed by C.A.L. are similar, our description will be limited to a system which varies only longitudinal motions.

One type of the longitudinal motion ("short period") consists of a relatively rapid oscillation whose period may range from as low as one second to as much as five seconds. Damping of the oscillation may range from quite heavy to rather light. Assuming that the inertia characteristics (mass, mass distribution) of a given airplane essentially are fixed, the exact values of the period and damping are determined by forces and moments which are produced by the pitching velocity and by the angle of attack and the rate-of-change of angle of attack. These forces and moments occur due to the direction and velocity with which the air flow strikes the fixed surfaces of the airplane (wing, tail, fuselage). Deflection of the control surfaces also produces moments and (secondarily) forces. That is, if the longitudinal control surface (elevator) of the airplane is moved in proportion to the pitching velocity or the angle of attack and rate at which the angle of attack changes, the forces and moments acting on the airplane will be modified and the stability of the airplane will be changed.

Required elevator motions can be obtained by sensing the required motions of the airplane and converting this sensed information into electrical signals. (Pitching velocity is measured by a restrained gyroscope and angle of attack by a vane similar to a miniature weather vane.) These signals are added together with similar signals produced by the pilot when he moves his controls. The sum of these signals commands the servo motor which deflects the elevator to a position corresponding to the command received by the servo system. The servo motor may be either an electrical motor or a hydraulic or pneumatic actuator. (Hydraulic actuators have been used by C.A.L. because of their fast response and compact design.) Simply by turning a knob in the cockpit, the stability and control of the airplane can be varied easily and rapidly through wide ranges in flight.

The pilot's control in the cockpit should not move when the elevator is deflected by the servo actuator. Such movement would distract the pilot who usually controls the movement of the control column himself. Therefore, a mechanical device is provided which permits him to connect or disconnect the control column from the elevator at will. When the column is mechanically connected and the servo equipment is turned off, the airplane may be flown normally. All the variable stability airplanes developed by C.A.L. have been equipped with dual controls. The copilot's controls have been left mechanically connected to the control surfaces at all times and several methods have been incorporated for instantaneously disengaging the servo equipment in the event of malfunction. Thus, the copilot is able to assume normal control of the airplane at any time necessary. Although multiple safety devices have been incorporated in all the variable stability aircraft developed by C.A.L., none of them has had to be used in flight.

Since the pilot's control column is not mechanically connected to the elevator, control forces must be supplied by auxiliary mechanical means. A characteristic of the variable stability airplane, however, is its ability readily to vary the magnitude of the control forces required for maneuvering the airplane so that research may be performed to determine desirable force levels. These forces are obtained by a hydraulic actuator attached to the control column. The amount the column moves for a given force can be related to the speed at which the airplane is flying, with less column motion occurring for a given applied force at higher speeds. This corresponds to the type of control force variation which is experienced when the force is obtained directly from aerodynamic reactions on the elevator. Control column motions proportional to angle of attack variations can also be produced by the column actuator. This represents another characteristic of control forces derived from aerodynamic reactions. Thus, forces analogous to those produced aerodynamically, but of variable level, can easily be obtained. It also is possible to simulate control force gradients which are independent of speed, or which are results of normal acceleration, pitching velocity, or other motions of the airplane. Various amounts of control system friction and nonlinear forces can also be simulated. The versatility and adjustability of this control-force device has rendered it an excellent tool for flight research.

The variable stability airplane is a flying laboratory. It permits the translation of the qualitative requirements of pilots into quantitative design recommendations and gives a preview of how predicted unconventional characteristics of future aircraft will be received by pilots. It transfers the probable acceptability of new flight characteristics from the realm of speculation to the area of experimental determination. Thus, it is an important tool in obtaining answers to problems which have plagued the aeronautical engineer throughout the history of aircraft.

REPORTS

"ARTIFICIAL STABILITY INSTALLATION IN B-26 AND F-94 AIRCRAFT," Kidd, E. A.; C.A.L. Report TB-757-F-9; WADC TR 54-441.

"FLIGHT RESEARCH UTILIZING VARIABLE STABILITY AIRCRAFT," Breuhaus, W.; paper presented at twenty-third annual meeting of the Institute of Aeronautical Sciences.

"EVALUATION OF ELEVATOR FORCE GRADIENTS AND TYPE OF FORCE FEEL IN A B-26 AIRPLANE," Newell, F., Campbell, G.; C.A.L. Report No. TB-757-F-10; WADC TR 54-442.

About the Authors...

ABRAHAM HERTZBERG began work on hypersonic testing theories in 1946. Following a period with the U.S. Army at Wright-Patterson Air Force base, where his group flight-tested transport and attack bombers, he was transferred to the Aberdeen Wind Tunnel. There he became engaged in the early missile projects. Three years later, in 1949, when writing a thesis on shock wave theory as a requirement for his Master of Aeronautical Engineering degree from Cornell University, he became enthusiastic over the many uses of non-steady shock waves in aerodynamics. In 1950 he started to work on the original C.A.L. hypersonic study.

After receiving his Bachelor of Aeronautical Engineering degree from Virginia Polytechnic Institute in 1943, Mr. Hertzberg joined the Curtiss-Wright Corporation as a test aerodynamicist in the Laboratory's eight-foot wind tunnel. Just prior to his post-graduate work at Cornell University in 1949 he returned to the Laboratory (which had then been incorporated as C.A.L.) to work for three months in the supersonic wind tunnel.

While attending Cornell University he was made assistant and associate research aerodynamicist in the campus laboratory. Since his return to C.A.L. he has been engaged in many projects and authored reports and papers on wind-tunnel testing, jet propulsion, shock tubes and hypersonic flow research. He was appointed a section head in Aerodynamic Research in 1954.

He is a member of Sigma Xi, professional research society.

WALDEMAR BREUHAUS reports that his initial interest in the specialized field of aircraft stability and control came about by accident. Thirteen years ago a suggestion from his chief that he assist with aileron aerodynamic design work sparked a keen enthusiasm for the evaluation of aircraft handling qualities. Mr. Breuhaus has been engaged in stability and control research ever since and the professional interest he has in this work is further reinforced by his personal interest as a private pilot (he has logged about 900 hours).

Mr. Breuhaus received a Bachelor of Science degree in Aeronautical Option Engineering from the Carnegie Institute of Technology in 1940. Immediately after graduation he joined the Aerodynamics and Flight Test Section of Vought-Sikorsky Aircraft. He remained with the Chance-Vought Division when Vought and Sikorsky divided into separate divisions of the United Aircraft Corporation in 1943. Although he worked on general aerodynamics and flight test analysis, he specialized principally in stability and control work and he was in charge of the Stability and Control Group from 1942 to 1946.

He joined C.A.L. in November, 1946, due to his interest in the flight stability work then being performed in the Flight Research Department. He was in charge of the Aeronautical Engineering Section of that department and in 1949 he was appointed Assistant Head of Flight Research.

He is a member of the Institute of Aeronautical Science, New York State Professional Engineers, Tau Beta Pi, Sigma Xi.

Recent C. A. L. PUBLICATIONS

"A FLUTTER THEORY FOR A FLEXIBLE HELICOPTER ROTOR BLADE IN VERTICAL FLIGHT," Chang, T.T.; C.A.L. Report No. SB-862-S-1; 73 pages (July 1954).

The derivation of the equations of motion of a fluttering helicopter rotor blade in vertical flight is described.

"A NOVEL HOLDING PATTERN FOR INBOUND AIRPLANES," Young, C. E.; paper presented at National Conference on Airborne Electronics; 8 pages (May 1955).

A proposed holding pattern simulated at C.A.L. by using a Link trainer is described in this paper.

"A STUDY OF SIMULATORS FOR THE LATERAL MOTIONS OF AN AUTOMOBILE," Fonda, A. G.; C.A.L. Report No. YA-804-F-2; 47 pages (October 1954).

The entire field of simulators for the lateral behavior of the automobile has been approached by the use of network diagrams, based on the equations of motion for a simplified automobile.

"AN ANALOG SURFACE FUNCTION GENERATOR," Earshen, J.; paper presented at National Conference on Airborne Electronics; 4 pages (May 1955).

An analog surface function generator developed to specifications which require only approximate representation of surfaces is described in this paper.

"AUTOMOBILE CRASH SAFETY RESEARCH," Smith, A. C.; C.A.L. Report No. YB-846-D-2; 61 pages (April 1955).

Results of three independent phases of auto safety investigations conducted for Liberty Mutual Insurance Company are described. Program included development of impact padding package for auto instrument panel installation, evaluation of an impact resistant auto fender material and design of an auto crash safety door lock.

"DESIGN, FABRICATION AND INSTALLATION OF CW 185 ()MPS AIR SUPPORTED RADOME," Bird, W. W.; C.A.L. Report No. UB-565-J-1; 57 pages (May 1949).

This report describes a spherical air supported radome designed for SCR-584 and AN/MPG-2 radar equipment.

"DEVELOPMENT OF HEAT-RESISTANT FOAMED-IN-PLACE DIELECTRIC CORE MATERIALS FOR SANDWICH RADOMES," Campagna, P. J., Preston, H. M., Wahl, N. E.; C.A.L. Report No. UB-691-M-18; WADC TR 54-249; 199 pages (March 1954).

This report summarizes work and accomplishments of a program to develop heat-resistant core materials for sandwich radomes.

"EXPERIMENTAL INVESTIGATIONS OF HEAT TRANSFER ON A 10-PERCENT DOUBLE-WEDGE AIRFOIL AT MACH NO. 2.0," Bartlett, G. E., Hilton, J. H., Vidal, R. J., Woolard, H. W.; C.A.L. Report No. CM-832; Bureau of Ordnance Contract NO-rd-14523; 95 pages (January 1955).

This report summarizes an experimental investigation to determine the temperature-recovery, heat-transfer and boundary-layer characteristics of a 10-percent-thick, two-dimensional, double-wedge airfoil.

"IMPROVING AIRPLANE HANDLING CHARACTERISTICS WITH AUTOMATIC CONTROLS," Muzzey, C. L.; paper presented to American Society of Mechanical Engineers; 13 pages (April 1955).

This paper describes a mode of airplane flight in which the aircraft is under the joint control of a human pilot and automatic control system.

"INTERACTION BETWEEN PRESSURE WAVES AND FLAME FRONTS," Markstein, G. H.; Schwartz, D.; reprinted from "Jet Propulsion," 6 pages (April 1955).

The shock tube technique was chosen as a convenient means for subjecting a flame front to controlled pressure wave disturbances to explore interaction between pressure waves and flame fronts. The project is reported in this article.

"INTERMITTENT STRESSING AND HEATING TESTS OF AIRCRAFT STRUCTURAL METALS, PART II," Guarnieri, G. J.; C.A.L. Report No. KB-685-M-14; WADC TR 53-24; 91 pages (May 1954).

The high-temperature, creep-rupture properties of six sheet alloys having application to aircraft design were investigated under conditions of intermittent load and temperature for comparison with their corresponding temperature-constant load behavior.

"LOW-SPEED PRESSURE DISTRIBUTIONS FOR A SERIES OF LOW-ASPECT-RATIO WINGS WITH VARIOUS EDGE SHAPES," Aerodynamic Research Department Staff; C.A.L. Report No. AF-743-A-7; 24 pages (August 1954).

Some of the pressure distribution data for a series of fifteen low-aspect-ratio wings tested in the Consolidated-Vultee Aircraft Corporation wind tunnel under U.S. Air Force contract are presented in this report.

"THERMOELECTRIC COOLING OF ELECTRONIC DEVICES," Welsh, J. P.; C.A.L. Report No. HF-845-D-13; Bureau of Ships Contract NObsr-63043; 12 pages (March 1955).

This report presents the findings from an investigation of the feasibility of the thermoelectric cooling of electronic devices.

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